Original Article
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Percutaneous Transpedicular Intravertebral Cage Augmentation with Short-Segment Fixation Using Specially Designed Cannulated Cage Trials for Advanced Kümmell Disease: A Preliminary Study Comparing with Vertebroplasty with Short-Segment Fixation

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Background: The treatment of Kümmell disease (KD) is controversial. Corpectomy and reconstruction or osteotomy with long-level fusion was traditionally performed for the advanced KD. However, these procedures can be disadvantageous for elderly patients. Several alternative surgical procedures including transpedicular intravertebral cage augmentation (TPICA) or vertebroplasty (VP) combined with short-segment fixation (SSF) have been suggested to minimize the surgical burden. This study aimed to compare the outcomes of percutaneous TPICA plus SSF with VP plus SSF for advanced thoracolumbar (T11–L2) KD and to introduce our novel percutaneous TPICA technique using specially designed cannulated cage trials.

Methods: We devised specially designed cannulated cage trials to make the TPICA procedure safer and more reproducible, minimizing the risk of the pedicle medial wall violation. All consecutive patients who underwent percutaneous TPICA or VP combined with SSF for advanced thoracolumbar KD, from January 2021 to June 2022, with ≥ 1-year follow-up at a single institution, were included. Perioperative details, clinical outcomes (visual analog scale and Oswestry Disability Index), and radiological outcomes (anterior vertebral body compression percentage and vertebral kyphotic angle [VKA] of the fractured vertebra, and local Cobb angle [LCA]) were collected and compared between the groups.

Results: A total of 42 patients were enrolled, with 21 patients in each group. There were no patients with pedicle medial wall fracture in the TPICA group. Both procedures provided significantly favorable radiological outcomes compared to those preoperatively. No significant differences were observed in the changes over time in all radiological parameters between the groups. Loss of correction during the follow-up period was significantly smaller in patients with TPICA than in those with VP in VKA (median [interquartile range], 2.15 [0.30–2.80] vs. 2.90 [0.90–6.53]; $p = 0.030$) and LCA (2.70 ± 2.90 vs. 5.17 ± 4.40, $p = 0.037$).

Conclusions: Both procedures are minimally invasive and useful options for advanced KD, especially for elderly patients with high comorbidity. Our novel percutaneous TPICA technique using cannulated cage trials, being safer and more reproducible, may allow spine surgeons to easily perform TPICA.

Keywords: *Spinal fractures, Osteonecrosis, Kümmell disease, Transpedicular intravertebral cage augmentation*

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With the advent of an aging society, the incidence of osteoporotic vertebral compression fractures (OVCFs) has been increasing.[1] Most patients with OVCFs experience considerable pain relief with progression of fracture union and spinal instability through conservative treatments; nevertheless, the incidence of nonunion and intravertebral vacuum cleft (IVC) was reported to be approximately 13.5% and 7%–13%, respectively.[2-4] Nonunion of OVCFs may result in noticeably impaired activity of daily living. Kümmell disease (KD), first presented by Hermann Kümmell in 1890s, was initially defined as delayed posttraumatic vertebral body collapse after asymptomatic minor spinal trauma.[5] Recently, KD has been referred to by multiple synonymous terms, such as OVCFs nonunion, posttraumatic vertebral osteonecrosis, intravertebral pseudoarthrosis, IVC, and intravertebral instability.[3,4,6] KD may present with unrelenting pain, progressive kyphotic deformity, and delayed neurologic deficits without response to conservative treatment.[4,6]

A controversy exists in the treatment of KD. Percutaneous vertebroplasty (VP) and kyphoplasty have been reported to show satisfactory results in pain relief and improvement of the patients' quality of life in stages I and II KD.[7] However, these may be associated with recollapse of the vertebra and bone cement dislodgement.[8-10] For the advanced KD, stage III, corpectomy and reconstruction or osteotomy with long-level fusion were conventionally performed.[11,12] However, these procedures are technically demanding and associated with high surgical burden, including long operation time and significant blood loss, especially for elderly patients with serious comorbidities and poor bone quality. To resolve this concern, short-segment fixation (SSF) combined with VP and its efficacy have been reported.[9,13-15]

Meanwhile, several previous studies have proposed the transpedicular intravertebral cage augmentation (TPICA) technique for the treatment of advanced KD.[4,11,16] Percutaneously performed TPICA technique was also recently reported to preserve the paravertebral musculature.[17] TPICA procedure is expected to provide anterior column support with short operation time and low risk of damaging anterior visceral structures, achieved through a posterior approach only. In our institution, in the past few years, we have implemented percutaneous TPICA procedures with SSF for advanced KD, aiming to minimize the surgical burden. However, to the best of our knowledge, the outcomes of TPICA combined with SSF have never been investigated. In addition, there is a lack of literature comparing TPICA and another previously reported minimally invasive procedure, SSF combined with VP, despite their common goal of providing anterior column support with a low surgical burden. Therefore, the purpose of the current study was to compare the 1-year outcomes of percutaneous TPICA and VP combined with SSF for advanced thoracolumbar KD performed at a single institution and to introduce our novel percutaneous TPICA technique using specially designed cannulated cage trials.

METHODS

This retrospective case series was approved by the Institutional Review Board of Bumin Hospital Seoul (IRB No. BMH 2023-08-005), and patient consent was waived because of its study design.

Study Patients

We reviewed all consecutive patients who underwent percutaneous TPICA or VP combined with SSF for advanced KD at the thoracolumbar (T11–L2) junction, from January 2021 to June 2022, and were followed up for more than 1 year at a single institution. In our institution, surgical treatment was considered for patients with advanced KD, progression of kyphotic deformity due to vertebral body collapse and/or intravertebral instability depending on the position despite appropriate conservative management, and definite IVC. Specifically, percutaneous TPICA or VP combined with SSF was performed for advanced KD patients without neurologic deficits. The decision on the surgical method depended on the surgeon's preference, based on the intactness of the endplates and pedicle size. Patients with KD above T11 or below L2, follow-up loss, or incomplete medical record documentation were excluded. A total of 57 patients who underwent percutaneous SSF combined with TPICA or VP were identified. Patients with KD above T11 or below L2 (n = 11), follow-up loss (n = 2), or incomplete medical record documentation (n =

2) were excluded, leaving 42 patients in total. Both TPICA and VP groups included 21 patients each.

Surgical Procedures Using Specially Designed Cannulated Cage Trials

The TPICA procedure was indicated for the patients with both intact upper and lower endplates or those with only small endplate breakage at the fractured vertebra, provided it was sufficient to support the entire surface of the endplates. The insertion side of intravertebral cage was preoperatively determined based on the integrity of the endplates and the degree of vertebral body collapse on each side. First, the side with an intact endplate was preferred. If both sides of the endplates were intact, we chose the side with greater vertebral body collapse to increase height and achieve balanced alignment. The side with a pedicle fracture was avoided. The ideal trajectory for intravertebral cage insertion through the pedicle was determined by measuring preoperative computed tomography (CT) scan images.

Four surgeons from a single institution (GC, YK, MSK, and HYS) performed operations with same surgical procedures under general anesthesia. The fractured vertebra and segments to be instrumented were identified using C-arm fluoroscopy. Bilateral vertical skin incisions were made and extended down to the subfascial plane. A cannulated bone biopsy needle with stylet was inserted via the pedicle of the fractured vertebra along the determined trajectory. To minimize the risk of violating the medial pedicle wall, caution was exercised to avoid coming too close to the pedicle medial wall on the anterior-posterior view. This was done when the needle tip was just passing the posterior wall of the vertebral body on the lateral view, taking into consideration the volume of the cage. After removing the stylet, the guide wire was passed through the cannulated needle. Following the cannulated needle removal, a sequential dilator system was applied, and tubular retractor system was placed to protect the muscle. The serial tapping was performed in increasing order of diameter until reaching 10 mm, aiming to induce the plastic deformation of the pedicle.[17] The specially designed cannulated cage trials were sequentially inserted through the guide wire with increasingly larger trials until the desired height (Fig. 1). During this stage, we thinned or slightly cracked the superolateral aspect of the pedicle for patients with too small pedicle to prevent the breakage of the medial or inferior pedicle wall. The restored vertebral body height was confirmed on the C-arm lateral view during the procedures. Finally, the banana-shaped cage (EIT Cellular Titanium or Crescent; Medtronic) filled with bone morphogenetic protein (Novosis, CGbio) was inserted inside the vertebral body (Fig. 2). Pedicle screws were percutaneously inserted into the fractured vertebra via the other pedicle and the adjacent vertebrae, positioned just above and below the fractured vertebra. All procedures were performed under the guidance of intraoperative C-arm fluoroscopy.

Data Collection and Outcome Assessment

We retrospectively reviewed the electronic medical records and measured the radiological parameters preoperatively, immediately postoperatively, and 1 year postoperatively. We collected data on patient demographics (sex and age), preoperative bone mineral density, preoperative comorbidities, and perioperative details (the level of fractured vertebra, cement augmentation of pedicle screw fixation [PSF], intraoperative estimated blood loss [EBL], and duration of surgery). Regarding preoperative comorbidities, the American Society of Anesthesiologists physical status classification system score was collected from the preoperative anesthesia record, which was documented by the anesthesiologists. The clinical outcomes were evaluated based on the visual analog scale (VAS) and Oswestry Disability Index (ODI).

Radiological parameters included vertebral kyphotic angle (VKA) of the fractured vertebra, local Cobb angle

Fig. 1. (A) Specially designed cannulated cage trials with different sizes. (B) A view showing the cannulation hole at the tip of a cage trial. (C) A cage trial with a guide wire inside its cannulation hole.

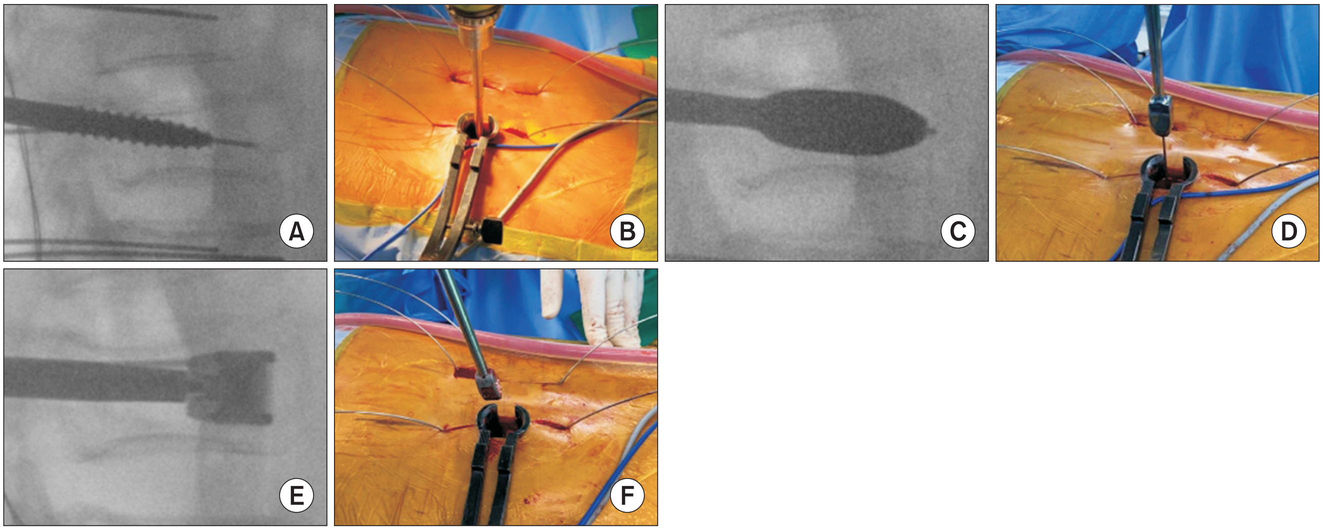

Fig. 2. Percutaneous transpedicular intravertebral cage augmentation technique using specially designed cannulated trial instruments under the guidance of intraoperative C-arm fluoroscopy. (A, B) Serial tapping in increasing order of diameter over the guide wire to induce the plastic deformation of the pedicle. (C, D) Percutaneous insertion of a cannulated cage trial over the guide wire. (E, F) Percutaneous insertion of the banana-shaped cage into the fractured vertebra.

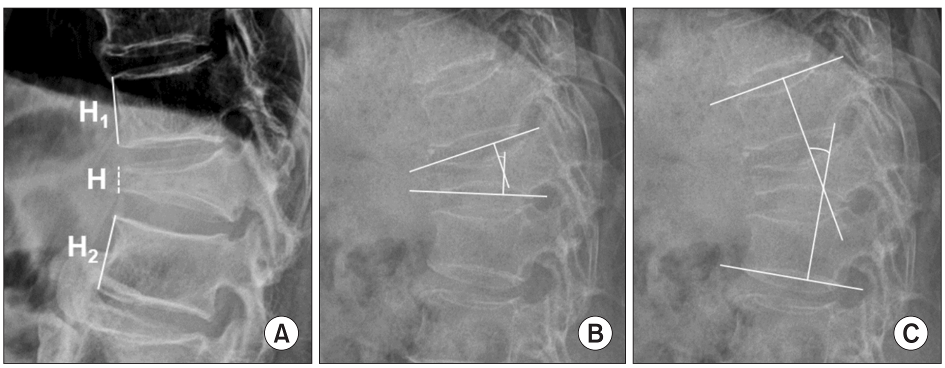

Fig. 3. Measurements of radiological parameters using a standing neutral lateral plain radiograph. (A) Anterior vertebral body compression percentage (AVCP). AVCP = 100 × [(H1 + H2) / 2– H] / (H1 + H2) / 2. H: anterior vertebral body height (AVH) of the fractured vertebra, H1: AVH of the above vertebra, H2: AVH of the below vertebra. (B) Vertebral kyphotic angle. (C) Local Cobb angle.

(LCA), and anterior vertebral body compression percentage (AVCP), which were measured using standing neutral lateral plain radiographs (Fig. 3). VKA was defined as the angle between the upper and lower endplates of the fractured vertebra.[18,19] LCA was defined as the angle between the upper endplate of the superior adjacent vertebra and the lower endplate of the inferior adjacent vertebra.[7] AVCP was defined as the ratio of the anterior vertebral height (AVH) loss compared to the mean value of the AVH of the adjacent vertebrae.[20] Radiological parameters were measured twice with an interval of 4 weeks by a fellowship-trained orthopedic spine surgeon with 5 years of experience (SCP). The mean values of the parameters were used for the analysis.

Statistical Analysis

Comparative analyses of baseline characteristics were performed to determine any differences between the 2 procedures using the Student *t*-test (mean ± standard deviation) or Mann-Whitney test (median, interquartile range) for continuous variables, depending on the normality, and the chi-square test or Fisher's exact test for categorical variables. To compare the preoperative and postoperative 1-year radiological parameters, a paired *t*-test was conducted for both groups. Comparison of changes in the radiological parameters over time between the 2 procedures was analyzed using repeated measures analysis of variance (RM-ANOVA). Additionally, interval changes in the radiological parameters between the immediate postoperative period and the last follow-up were compared between the 2 groups using either the Student *t*-test or the Mann-Whitney test to assess the maintenance of these parameters. Comparison of the clinical outcomes was performed using the Mann-Whitney test. All statistical analyses were performed using IBM SPSS statistics version 25.0 (IBM Corp.). The p-values < 0.05 were considered statistically significant.

RESULTS

Study Patients and Baseline Characteristics

There were 27 women and 15 men, with a mean age of 73.43 ± 10.63 years. The level of fractured vertebra was T11 in 1 (2.4%), T12 in 19 (45.2%), L1 in 18 (42.9%), and L2 in 4 patients (9.5%). Regarding the perioperative details, there was no significant difference in proportion of cement-augmented PSF, duration of surgery, and EBL between the 2 groups (Table 1). There were no patients with the pedicle medial wall fracture.

Comparison of Radiological Parameters between Preoperative and Postoperative 1-Year Status

Both percutaneous TPICA and VP with SSF had significantly improved radiological outcomes at the last follow-up compared to preoperative values, based on a paired t-test ($p < 0.05$) (Table 2). Despite some loss of correction during the follow-up period in all radiological parameters in both groups, the differences between preoperative and postoperative 1-year status were statistically significant.

Comparison of Radiological And Clinical Outcomes between Groups

In the RM-ANOVA, there was no significant difference in the changes over time in all radiological parameters between the groups, as shown in Table 3 and Fig. 4 (AVCP: $p = 0.098$, partial $\eta^2 = 0.073$; VKA: $p = 0.364$, partial $\eta^2 = 0.023$; and LCA: $p = 0.065$, partial $\eta^2 = 0.131$). Although preoperative AVCP was significantly larger in patients with

Table 1. Comparison of Baseline Characteristics and Perioperative Information between Groups

Variable	TPICA + SSF (n = 21)	VP + SSF (n = 21)	p-value
Age (yr)	75.0 (70.5–82.5)	77.0 (67.0–79.0)	0.772*
Sex			0.334†
Female	15 (71.4)	12 (57.1)	
Male	6 (28.6)	9 (42.9)	
BMD, T-score	–2.33 ± 1.47	–2.51 ± 0.97	0.631‡
Fractured vertebra			0.859†
T11	0	1 (4.8)	
T12	10 (47.6)	9 (42.9)	
L1	10 (47.6)	8 (38.1)	
L2	1 (4.8)	3 (14.3)	
ASA			0.238§
2	15 (71.4)	19 (90.5)	
3	6 (28.6)	2 (9.5)	
Pedicle screw fixation			0.753†
Cement-augmented	8 (38.1)	9 (42.9)	
Non-cement-augmented	13 (61.9)	12 (57.1)	
Duration of surgery (min)	100.0 (90.0–145.0)	90.0 (75.0–125.0)	0.060*
EBL (mL)	162.86 ± 64.51	155.24 ± 56.89	0.687‡

Values are presented as median (interquartile range), number (%), or mean ± standard deviation.
TPICA: transpedicular intravertebral cage augmentation, SSF: short-segment fixation, VP: vertebroplasty, BMD: bone mineral density, ASA: American Society of Anesthesiologists Physical Status Classification System; EBL: estimated blood loss.
*Mann-Whitney test. †Chi-square test with continuity correction. ‡Student t-test. §Fisher's exact test.

Table 2. Comparison of Radiological Parameters between Preoperative and Postoperative 1-Year Status

Variable	Preoperative	Postoperative 1 yr	*p*-value
TPICA+SSF			
AVCP (%)	13.12 ± 4.16	6.10 ± 4.13	< 0.001*
VKA (°)	18.90 ± 5.45	11.87 ± 4.82	< 0.001*
LCA (°)	23.69 ± 8.71	15.05 ± 5.04	< 0.001*
VP+SSF			
AVCP (%)	9.87 ± 4.94	5.76 ± 2.76	0.001*
VKA (°)	17.99 ± 6.59	11.84 ± 3.21	< 0.001*
LCA (°)	19.09 ± 8.98	15.88 ± 10.00	0.042*

Values are presented as mean ± standard deviation.
TPICA: transpedicular intravertebral cage augmentation, SSF: short segment fixation, AVCP: anterior vertebral body compression percentage, VKA: vertebral kyphotic angle, LCA: local Cobb angle, VP: vertebroplasty.
*Indicates statistical significance ($p < 0.05$).

Table 3. Comparison of Radiological and Clinical Outcomes between Groups

Variable	TPICA + SSF (n = 21)	VP + SSF (n = 21)	*p*-value
Radiologic outcome			
AVCP (%)			0.098*
Preoperative	13.12 ± 4.16	9.87 ± 4.94	
Postoperative	4.18 ± 3.66	2.38 ± 2.04	
Last follow-up	6.10 ± 4.13	5.76 ± 2.76	
Loss of correction	1.77 (0.44–2.44)	2.23 (1.19–5.05)	0.116†
VKA (°)			0.364*
Preoperative	18.90 ± 5.45	17.99 ± 6.59	
Postoperative	10.04 ± 3.31	7.78 ± 3.99	
Last follow-up	11.87 ± 4.82	11.84 ± 3.21	
Loss of correction	2.15 (0.30–2.80)	2.90 (0.90–6.53)	0.030†,§
LCA (°)			0.065*
Preoperative	23.69 ± 8.71	19.09 ± 8.98	
Postoperative	12.35 ± 4.55	10.71 ± 8.66	
Last follow-up	15.05 ± 5.04	15.88 ± 10.00	
Loss of correction	2.70 ± 2.90	5.17 ± 4.40	0.037‡,§
Clinical outcome			
ODI			
Preoperative	37.0 (28.5–53.5)	41.0 (30.0–46.0)	0.900†
Last follow-up	16.0 (12.0–21.0)	13.0 (12.0–18.0)	0.240†
VAS			
Preoperative	6.0 (5.0–7.5)	6.0 (5.0–7.5)	0.540†
Postoperative	3.0 (1.0–4.0)	2.0 (1.0–3.0)	0.145†

Values are presented as mean ± standard deviation or median (interquartile range).
TPICA: transpedicular intravertebral cage augmentation, SSF: short-segment fixation, VP: vertebroplasty, AVCP: anterior vertebral body compression percentage, VKA: vertebral kyphotic angle, LCA: local Cobb angle, ODI: Oswestry Disability Index, VAS: visual analog scale.
*Repeated measures analysis of variance. †Mann-Whitney test. ‡Student *t*-test. §Indicates statistical significance ($p < 0.05$).

TPICA than in those with VP (13.12 ± 4.16 vs. 9.87 ± 4.94, $p = 0.027$), there was no significant difference in postoperative and last follow-up AVCP between the groups, based on a *t*-test. Regarding maintenance of the radiological parameters during the follow-up period, loss of correction was significantly smaller in patients with TPICA than in those with VP in VKA (median [interquartile range], 2.15 [0.30–2.80] vs. 2.90 [0.90–6.53]; $p = 0.030$) and LCA (2.70 ± 2.90 vs. 5.17 ± 4.40, $p = 0.037$). Comparisons of clinical outcomes including ODI and VAS showed comparable scores preoperatively and at the last follow-up between the 2 groups (Table 3).

DISCUSSION

Several modified surgical procedures for advanced KD have been proposed to reduce the surgical burden, especially for elderly patients with high comorbidity. Among them, TPICA with SSF has been reported to achieve anterior column support and acceptable restoration of the collapsed vertebral height, with short surgical time and low blood loss. However, the most devastating complication of TPICA technique would be the pedicle medial wall fracture and resultant neurological injuries. Therefore, the cannulated cage trial was devised to maintain the initially aimed trajectory by inserting the cage trials over the guide wire and reduce the risk of pedicle medial wall fracture consequently (Fig. 5). In addition, the specially designed cannulated cage trials of different sizes allow surgeons to enlarge the pedicle hole gradually until the desired height is reached, while keeping the trajectory.

Both percutaneous TPICA and VP combined with SSF showed favorable outcomes in this cohort. However, although preoperative AVCP of the TPICA group was statistically larger than that of the VP group, postoperative and last follow-up AVCPs of the TPICA group were statistically comparable to those of the VP group. Together

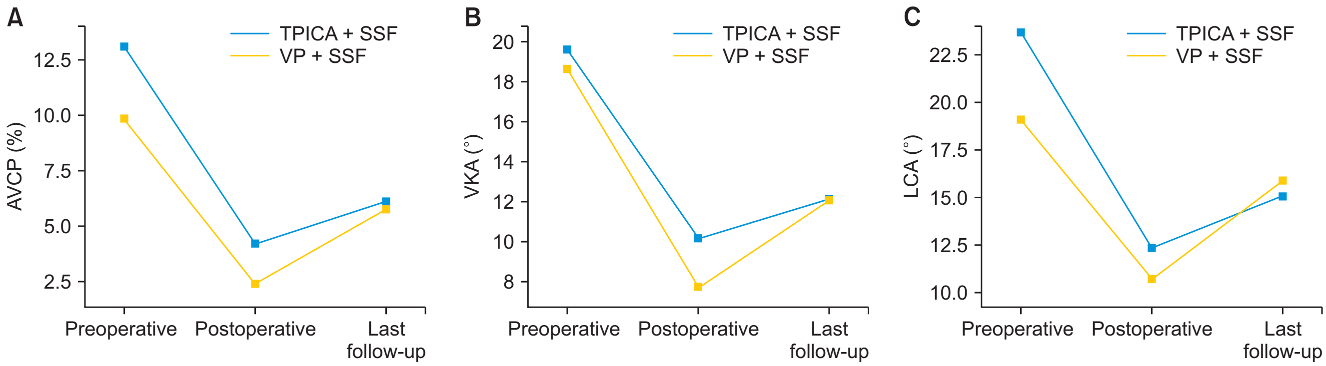

Fig. 4. Comparison of radiological parameters over time between 2 groups. (A) Anterior vertebral body compression percentage (AVCP). (B) Vertebral kyphotic angle (VKA). (C) Local Cobb angle (LCA). TPICA: transpedicular intravertebral cage augmentation, SSF: short-segment fixation, VP: vertebroplasty.

Fig. 5. Postoperative axial computed tomography image showing an intact medial wall of the pedicle after cage insertion.

with positional reduction facilitated by the prone position, the sequential tapping and cannulated cage trials insertion over the guide wire in increasing order of diameter and size might induce a gradual expansion of vertebral body. This, in turn, could lead to restoration of the vertebral height during the TPICA procedure. These results imply that TPICA can be an effective technique to restore the collapsed vertebra and sustain the restored vertebral height in advanced KD (Fig. 6).

Percutaneous TPICA with SSF represented better results than VP with SSF in the maintenance of VKA and LCA. In addition, there was a tendency for the TPICA group to be relatively superior to the VP group in the maintenance of AVCP, despite no significant difference. TPICA may have an advantage in terms of the maintenance of alignment and restored vertebral height because it would be able to maintain the vertebral body at least as high as the cage height, even in the case of poor bone healing. Moreover, our novel technique using the specially designed cannulated cage trials would be able to make the procedure safer and more reproducible, providing comparable results with VP plus SSF regarding EBL and duration of surgery, which would be suitable for elderly patients.

VP at the fractured vertebra can induce several catastrophic complications related to cement injection, such as bone cement leakage into the spinal canal or vascular structures, due to destruction of the vertebral wall.[21)] It may lead to thecal sac compression, pulmonary embolism, and even life-threatening respiratory problems.[1)] Furthermore, there are potential risks regarding cement loosening or dislodgement resulting from micromotion because bone cement cannot interdigitate with the trabecular bone under the circumstances of IVC.[4)] In contrast, TPICA procedure may have a potential to offer physiologic bone bridge between superior and inferior endplates.[16)] However, because CT scan was not consistently performed during the follow-up period in this cohort, it was not possible to assess the bone bridge formation or intravertebral bone union status. A well-designed study, evaluating the bone formation and biologic status inside the vertebral body after TPICA for advanced KD, should be conducted in the future.

In this cohort, the TPICA group included both cement-augmented and non-cement-augmented PSF patients. We experienced progression of kyphosis or recollapse of the fractured vertebra during the follow-up period in several patients with non-cement-augmented PSF. In subgroup analysis, the amount of LCA loss was significantly larger in patients with non-cement-augmented PSF than in those with cement-augmented PSF (3.83 ± 2.33 vs. 0.86 ± 2.89, p = 0.018). Although SSF has been performed

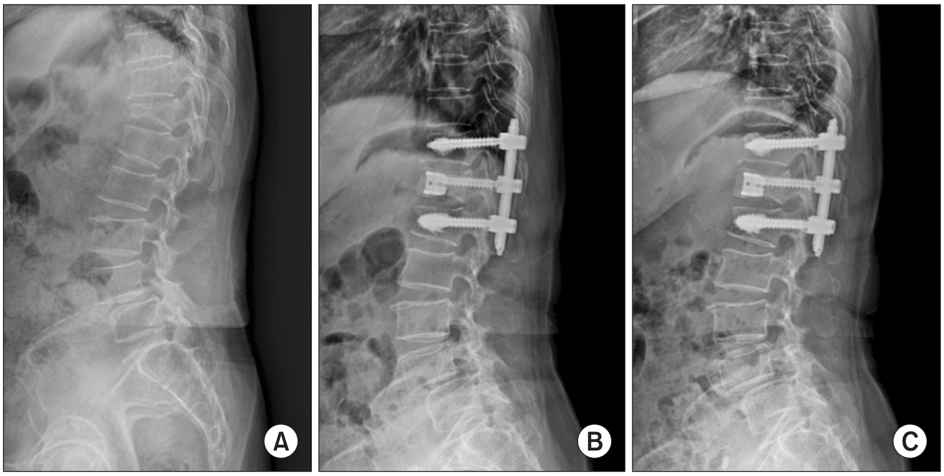

Fig. 6. A 72-year-old female patient with thoracolumbar Kümmell disease, who underwent percutaneous transpedicular intravertebral cage augmentation and cement-augmented short-segment pedicle screw fixation. (A) Preoperative standing lateral x-ray. (B) Immediated postoperative lateral x-ray showing the restored vertebral height and satisfactory alignment. (C) Follow-up x-ray at 1 year after surgery showing well-maintained alignment.

to reduce the surgical morbidity in spinal fractures,[9,13,15] it may have concerns for the stability of the construct. Meanwhile, cement-augmented PSF has been known to be effective for improving fixation strength in osteoporotic bone in previous studies.[22-24] In addition, SSF with cement-augmented PSF has been proposed as an effective treatment for KD.[25] Huang et al.[14] found that SSF with cement-augmented PSF for advanced KD was associated with lower EBL, shorter length of hospital stay, and comparable clinical and radiological outcomes compared to those with long-segment fixation. Consistent with these reports, our results showed that cement-augmented PSF would be beneficial for the maintenance of the alignment and stability compared to those with non-cement-augmented PSF in TPICA group. However, a well-designed prospective study with a larger sample size is needed to demonstrate the efficacy of cement-augmented PSF in the percutaneous TPICA with SSF for advanced KD.

In this study, the percutaneous TPICA with SSF was indicated for the delayed posttraumatic vertebral osteonecrosis with IVC and/or intravertebral instability without neurologic deficits. For patients with neurologic deficits or severe central canal encroachment due to bone fragments, we have opted for conventional open surgeries, including corpectomy or posterior decompression combined with long-level fusion. However, since intravertebral instability has been suggested as the predominant cause of neurologic deficits in previous studies,[4,6] the indication of percutaneous TPICA technique may be extended to include advanced KD with neurologic deficits caused by dynamic instability. Further studies are needed to establish the cutoff value of intravertebral instability or central canal encroachment, indicating when the percutaneous TPICA technique is appropriate.

Due to the nature of the TPICA procedure, there is a possibility of occasionally breaking the lateral wall of the pedicle in cases of KD involving the vertebra with small pedicle. Patients with pedicle lateral wall fracture experienced flank pain on the side ipsilateral to the cage insertion. This pain is thought to be associated with the irritation of the nerve root. Among them, 1 patient with severe flank pain had difficulty in postoperative respiratory care during the immediate postoperative period, resulting in pneumonia. This patient recovered well with timely management. However, advanced surgical techniques or instruments are required to prevent this potential complication.

The present study has some limitations. First, the number of included patients was too small to generalize our results as a consistent phenomenon. There may be conditions or factors that have not been considered in this study. Second, the 1-year follow-up was relatively short to evaluate the stability and durability of these procedures, which requires long-term follow-ups. Third, owing to its retrospective study design, there may be selection bias or confounding factors that should have been covered. Despite these limitations, to the best of our knowledge, this is the first study to evaluate the outcomes of percutaneous TPICA combined with SSF for advanced KD. Moreover, we introduced our novel TPICA technique using the specially designed cannulated cage trials, enabling spine surgeons to perform the procedures easily by making them simple and safe.

Both percutaneous TPICA and VP combined with SSF could be considered minimally invasive and efficacious surgical options for advanced thoracolumbar KD, providing favorable clinical and radiological outcomes. In particular, our novel percutaneous TPICA technique, using the specially designed cannulated cage trials, can enhance the safety and reproducibility of the procedure. A cement-augmented PSF for stronger fixation should be considered to prevent recollapse of the restored vertebra and recurrent kyphosis progression of instrumented segments.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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